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MEASUREMENT OF DT NEUTRON-INDUCED ACTIVITY IN GLASS MICROSHELL LASER-FUSION TARGETS

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Measurement of DT neutron-induced activity in glass microshell laser-fusion targets*

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ABSTRACT

Laser-fusion targets consisting of DT gas contained in Teflon-coated glass microshells produce 14.1-MeV neutrons that can interact with the ^{28}Si nuclei in the glass to produce radioactive ^{28}Al. Using a very efficient collection-detection scheme that could detect the decay of 10% of the ^{28}Al created, we identified these nuclei by their 1.78-MeV gamma ray that decayed with a 2.2-min half-life. From the number of ^{28}Al nuclei created and the neutron yield the compressed glass areal density was found to be 0.0059 g/cm^2.

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In an imploded laser-fusion target consisting of DT gas encapsulated in a glass microshell, the thermonuclear neutrons activate the ^{28}Si atoms in the glass via the $^{28}Si(n,p)^{28}Al$ reaction. By knowing the neutron yield and the total number of ^{28}Al atoms created, the areal density ($\rho\Delta R$) of the compressed glass shell at the time of peak neutron production can be found.[1-3] The glass $\rho\Delta R$ can then be used as input to simple models or computer simulations to estimate the compressed density of the fuel. Here, we describe a recent experiment at the Lawrence Livermore Laboratory Shiva laser facility in which the activity found in the collected target debris was identified by its decay rate as ^{28}Al. The amount of activity was then used to derive the compressed glass $\rho\Delta R$.

The targets used in this experiment were glass microshells with inner diameters of 140 μm and wall thicknesses of 5 μm (Fig. 1). They were filled with a 10 mg/cm^3 equimolar mixture of DT gas, and coated with 15 μm of Teflon.[4] The glass constituents were 76% by weight SiO_2, 7.5% B_2O_3, 14% Na_2O, and 2.25% K_2O.

A laser energy of 4 kJ in a 200-ps Gaussian pulse was directed by 20 individually focused beams onto the target's Teflon ablator. The heating and subsequent blow off of the ablator compressed the glass pusher and the fuel. It was estimated from both optical and plasma calorimetry that 20% of the incident laser energy was absorbed. Typical neutron yields of 1 to 7×10^8 were obtained. Additional details of the experiment will be described in forthcoming articles.

A portion of the debris from the exploding target was collected by placing a 5-cm-diameter by 16.5-cm-long aluminum cylinder (collector) 1 cm from the target (Fig. 2). Opposite the collector, a dish-shaped tantalum reflector also 5 cm in diameter was placed at a distance of 2.5 cm from the target. The collector cylinder was lined with 20-μm-thick titanium foil with the front 3 cm covered with an additional 50-μm-thick layer of tantalum foil to protect against blast damage. It took 17 s for an automated system to withdraw the collector from the evacuated target chamber and transfer it to the counting facility.

The amount of collected debris was determined in two auxiliary experiments using identical targets and laser conditions to those described above. In these experiments,[3] however, the microshells were made slightly radioactive by placing them in a light-water reactor and allowing thermal neutron capture to create radioactive ^{24}Na ($t_{1/2}$ = 15 h) from the ^{23}Na in the glass. The fraction of target debris collected was then measured by determining the ratio of the ^{24}Na activity found on the collector foils following a laser shot to that known to be present in the target. The average amount of target debris collected in these two experiments was 55.3 ± 0.5%.

Both the ^{24}Na and ^{28}Al activities were measured with a 25-cm-diameter by 25-cm-long NaI (Tl) detector which had a 5-cm-diameter, 15-cm-deep well. The ^{28}Al decays with a 2.24-min half-life by the emission of a β^- particle followed by a 1.78-MeV gamma ray. The measured detection efficiency of the NaI(Tl) detector at 1.78 MeV was 33 ± 4%. A lead shield 10-cm thick surrounding the detector reduced the background in the 300-keV-wide, 1.78-MeV window to 88 counts/min.

In the $\rho\Delta R$ experiment, 4.1 kJ were delivered to the target in a 212-ps pulse producing a neutron yield of 6.7×10^8. The detector was loaded with the collector foils and switched on 1.36 min after the laser shot. An activity was then observed that decayed with a half-life of 2.16 ± 0.16 min, which gives us confidence that we are indeed measuring the 2.24-min activity from ^{28}Al (Fig. 3). Previous experiments reported in the literature did not have sufficient activity to identify the radioactive nuclide.[2]

Equation (1) relates the detected number of decays N_c to the total number of activated atoms created N* by accounting for the collection efficiency η_c, the detection efficiency η_d, the delay time between the laser shot and commencement of counting t, the counting interval Δt (taken to be 5 min), and the ^{28}Al decay constant λ:

$$N^* = \frac{N_c}{\eta_c \eta_d e^{-\lambda t}\left(1-e^{-\lambda \Delta t}\right)} . \tag{1}$$

The 770 net counts detected in the first 5 min of counting indicate that 7960 ^{28}Al atoms were created. Thus, we are able to detect nearly 10% of the <u>total</u> activation yield of the target. This clearly demonstrates the extreme sensitivity of neutron-activation technique. Using our more sophisticated β-γ coincidence counting technique[2] which reduces the background rates by a factor of 200, we are able to detect total activation yields of only 100 atoms.

The number of activated atoms created can now be related to an average $\rho\Delta R$ by equation (2), where Y_n is the neutron yield (6.7×10^8), σ is the ^{28}Si(n,p)^{28}Al cross-section (0.250 b), f is the fraction of ^{28}Si atoms in the pusher (0.25), A_w is the average atomic weight of the pusher (20 g), and A_o is Avogadro's number:

$$\rho\Delta R = \frac{N^*}{Y_n \sigma \, f \, A_o/A_w} = 5 \times 10^2 \; \frac{N^*}{Y_n} \; . \tag{2}$$

In this experiment, the pusher areal density was 0.0059 $\pm$ 0.0015 g/cm^2. This represents a 5.4-fold increase in the pusher $\rho\Delta R$ from its initial value. From this areal density, simple models and simulation codes suggest fuel densities of 1 to 2 g/cm^3 were attained.

Using an extremely efficient collection-detection system and a high yield target, we have measured a 2-min gamma ray activity at 1.78 MeV. We conclude that no nuclei could produce this signal other than ^{28}Al created in the pusher by the ^{28}Si(n,p)^{28}Al reaction with 14-MeV DT neutrons. The pusher areal density of 5.9 mg/cm^2 inferred from this measurement suggests a DT density at burn time of 1 to 2 g/cm^3.

REFERENCES

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[3]E. M. Campbell, H. G. Hicks, W. C. Mead, L. W. Coleman, C. W. Hatcher, J. H. Dellis, M. J. Boyle, J. T. Larsen, and S. M. Lane, Lawrence Livermore Laboratory Report No. UCRL-83072, 1979, submitted for publication, J. Appl. Phys.

[4]Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

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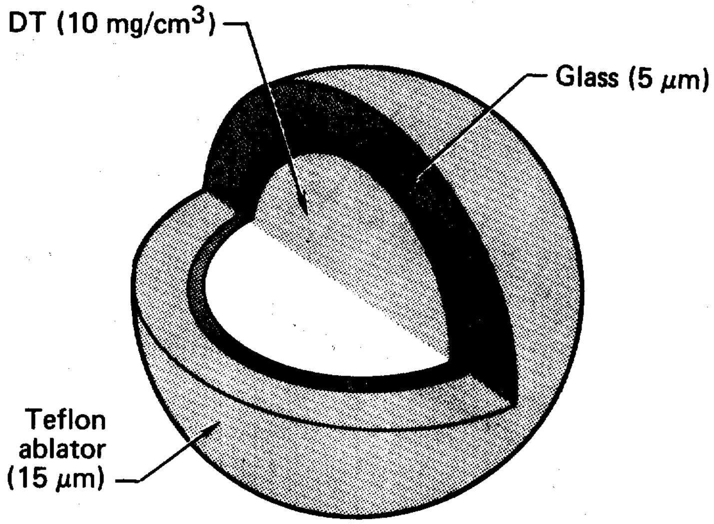
Figure Captions

FIG. 1. Laser-fusion target consisting of a Teflon-coated glass microsphere filled with 10 mg/cm^3 of DT gas.

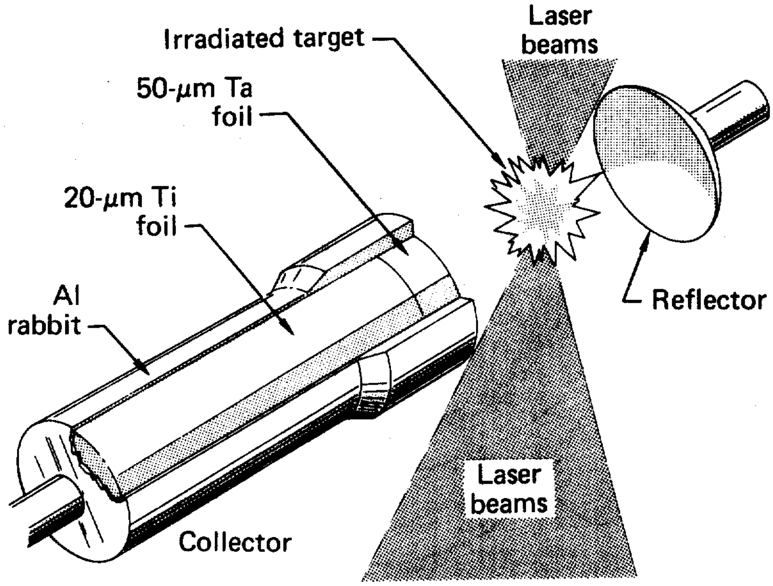
FIG. 2. Target debris collector. An aluminum tube lined with titanium and tantalum foil was placed 1 cm from the target opposite a dish-shaped reflector. With this arrangement, 55% of the target debris adhered to the foil.

FIG. 3. Decay curve obtained from gamma activity (1.63 to 1.93 MeV) detected in the collected target debris. The 2.2-min half-life indicates that we are observing ^{28}Al.

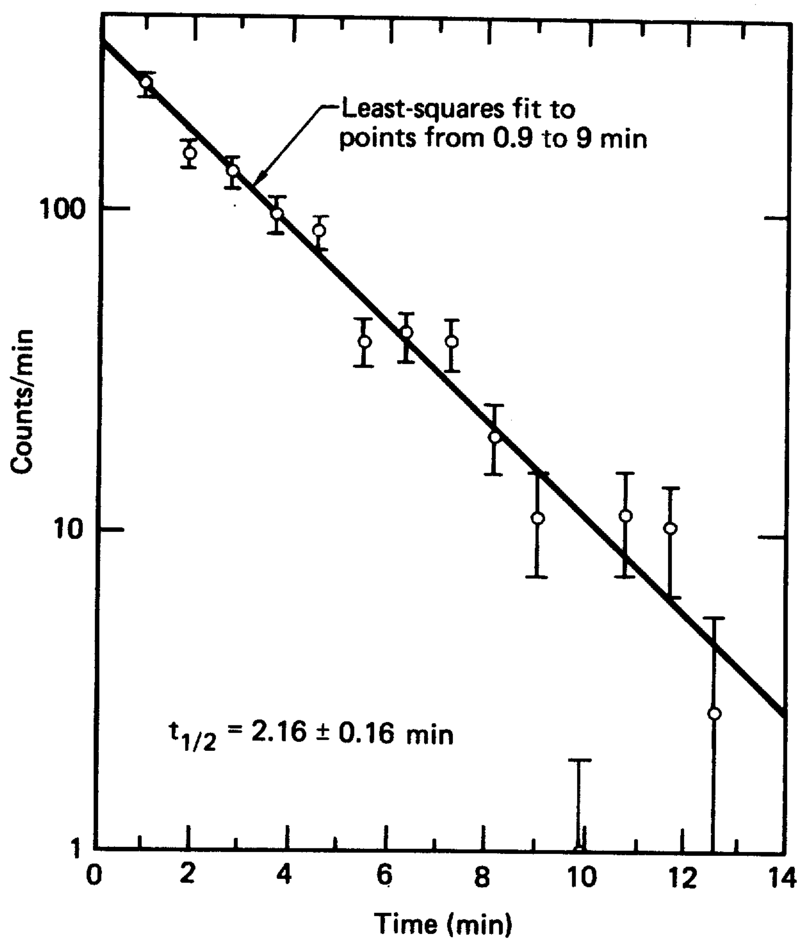


Initial inner diameter (~140 μm)

Lane - FIG. 1.


Irradiated target
Laser beams
50-μm Ta foil
20-μm Ti foil
Al rabbit
Reflector
Laser beams
Collector

Lane - FIG. 2.



Least-squares fit to points from 0.9 to 9 min
100
10
1
Counts/min
$t_{1/2}$ = 2.16 ± 0.16 min
0
2
4
6
8
10
12
14
Time (min)

Lane - FIG. 3.